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ENVIRONMENTAL EXPOSURE SYSTEM FOR
STUDYING AIR POLLUTION DAMAGE TO
MATERIALS

John W. Spence, et al

National Environmental Research Center
Research Triangle Park, North Carolina

January 1975

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
National Environmental Research Center
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ABSTRACT

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CONTENTS

<u>Section</u>	<u>Page</u>
LIST OF FIGURES	v
LIST OF TABLES	v
ACKNOWLEDGMENTS	vi
ABBREVIATIONS AND SYMBOLS	vi
INTRODUCTION	1
DESIGN FEATURES OF ENVIRONMENTAL SYSTEM	2
Airflow Details	2
Exposure Chambers	4
Pollutant Control System	6
CHAMBER EVALUATION AND OPERATION	11
Chamber Lighting	11
Pollutant Distribution	13
Control of Environmental Variables	14
SUMMARY	16
REFERENCES	16
APPENDIX A: ENVIRONMENTAL COMPONENTS	17
APPENDIX B: POWER DISTRIBUTION OF ENVIRONMENTAL SYSTEM	17
APPENDIX C: ELECTRICAL AND GAS LINE SCHEMATICS FOR NITROGEN DIOXIDE DILUTION SYSTEM	29
APPENDIX D: ELECTRICAL AND GAS LINE SCHEMATICS FOR SULFUR DIOXIDE DILUTION SYSTEM	33
APPENDIX E: SIMPLIFIED CIRCUITRY OF POLLUTANT CONTROLLER	37

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Environmental System Flow Diagram	3
2. Environmental Exposure Chambers	5
3. Exposure Chill Racks	5
4. Dilution System	7
5. Pollutant Controller	8

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Analysis of Variance for Initial Lamp Energy Data	11
2. Analysis of Variance for Lamp Energy Data	12
3. Analysis of Variance for Pollutant (NO ₂) Distribution within the Chambers	14
4. Control Capability of Environmental Variables within the Chambers	15

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The pollutant controllers were designed and built by Adgo, Inc., under contract to the Environmental Protection Agency.

ABBREVIATIONS AND SYMBOLS

ac	alternating current
°C	degrees Celsius (centigrade)
cm	centimeters
°F	degrees Fahrenheit
min	minute
mm	millimeters
m ³	cubic meters
NO ₂	nitrogen dioxide
N ₂ O ₄	nitrogen tetroxide
NO _x	oxides of nitrogen
O ₃	ozone
ppm	parts per million
psig	pounds per square inch gauge
SCR	silicone controlled rectifier
SO ₂	sulfur dioxide
µg	micrograms
µm	micrometers (microns)

ENVIRONMENTAL EXPOSURE SYSTEM FOR STUDYING AIR POLLUTION DAMAGE TO MATERIALS

INTRODUCTION

This report describes the design, hardware, operation, and safety features of a controlled-environment exposure system consisting of five chambers. The system is equipped with automatic controls for regulating temperature, humidity, dew/light cycle, and concentrations of sulfur dioxide, nitrogen dioxide, and ozone pollutants within each chamber. The description of the operational capabilities of the environmental system should be beneficial to those laboratories within the Environmental Protection Agency that are conducting controlled environmental effects research, as well as industrial and educational organizations conducting similar research.

The purpose of the environmental system is to provide simulated environments for conducting statistical experiments for determining pollutant damage to materials. Resulting information, such as predictive equations of dose-response relationships, will be used in setting secondary ambient air quality standards and in assessing economic damage to real property as specified in the Clean Air Amendments of 1970.¹

DESIGN FEATURES OF THE ENVIRONMENTAL SYSTEM

The controlled-environment exposure system consists of five chambers and necessary hardware to control the flow, concentration of pollutants (SO_2 , NO_2 , O_3), temperature, and relative humidity of the incoming air to each chamber. In addition, each chamber features a controlled dew/light cycle that simulates diurnal conditions. This allows the surfaces of exposed test specimens to absorb and concentrate gaseous pollutants as material surfaces do in the real world. The system was designed so that a continuous single-pass movement of air flows through each chamber, thereby preventing possible accumulation of material decomposition products. Hardware essential in assembling the environmental system is shown in Appendix A.

AIRFLOW DETAILS

Figure 1 shows a flow diagram of the environmental system, and Appendix B shows the interfacing of components. Ambient air is drawn into a galvanized steel duct (61 by 61 cm) and is filtered by a system that removes 99 percent of the 5- μm or greater particulate matter. The air next passes through a charcoal filter to remove gaseous contaminants, then to a dehumidifying/cooling system consisting of a chiller with glycol/water coolant and aluminum cooling coils. The cooling system has been equipped with a low-level cutoff switch that automatically shuts off the chiller if a loss of coolant occurs. The dehumidifying/cooling system conditions the clean air to about 1°C and 100 percent relative humidity.

The conditioned clean air now passes into an insulated manifold duct (40.6 by 40.6 cm, galvanized steel). The manifold distributes up to 3.4 m^3/min of clean air to each chamber through individual air supply ducts. Each air supply duct contains a heater and steam injection port to recondition the clean air to a specified temperature and humidity and a high-temperature sensor and cutoff to prevent overheating. From the air supply

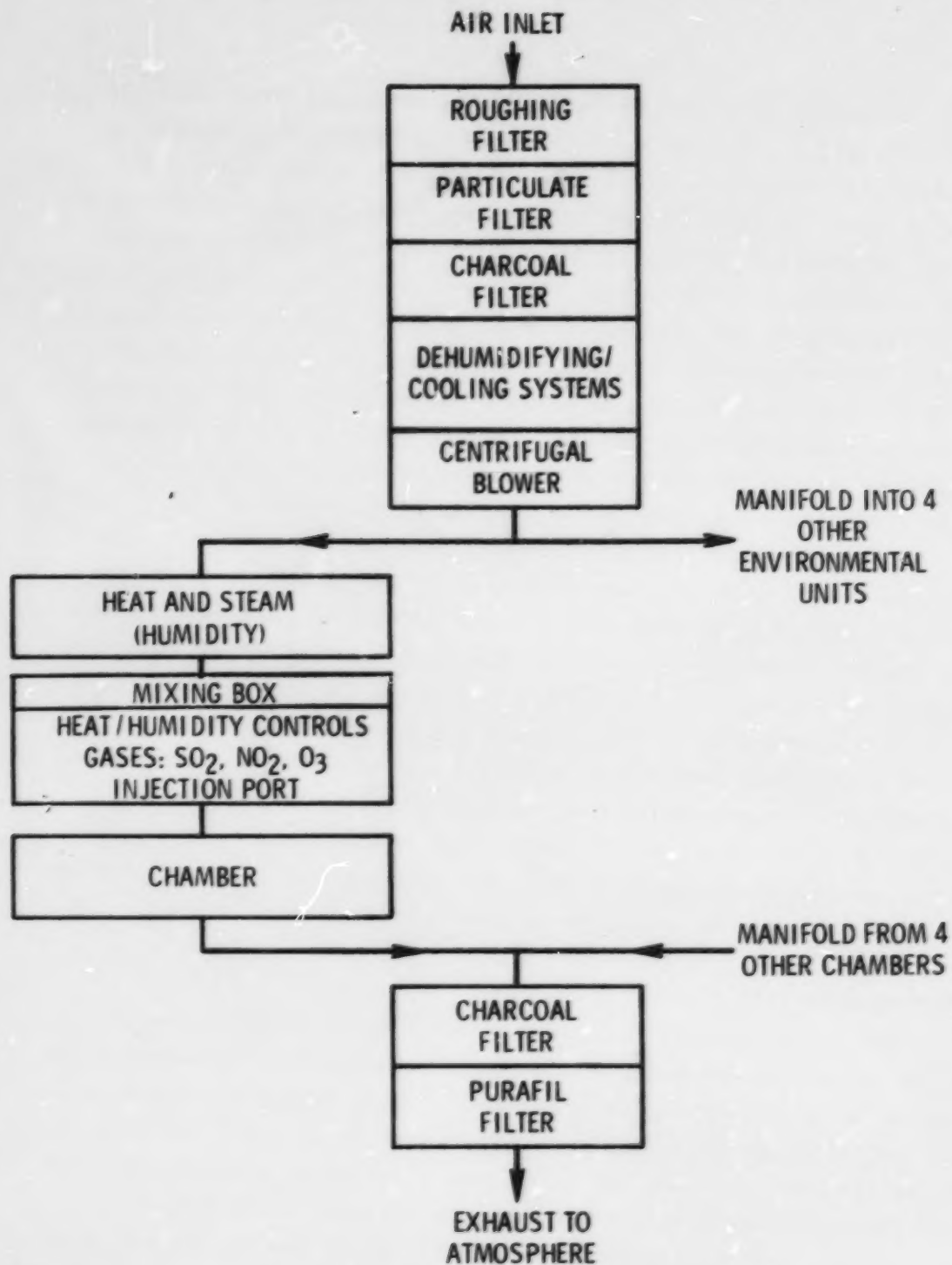


Figure 1. Environmental system flow diagram.

duct, the heated and humidified air flows through an insulated, flexible, vinyl tubing (10.2-cm diameter) to a mixing box that houses temperature and humidity control/recording sensors and separate injection ports for gaseous sulfur dioxide, nitrogen dioxide, and ozone pollutants. Injection of the pollutants is upstream of the humidity sensors. This feature prevents contamination of the sensor. The mixing box (galvanized steel coated with epoxy sealant) has fins on the inside walls to promote better dispersion of pollutants with the incoming air stream. The reconditioned, polluted air then flows into the base of a stainless steel chamber, across a plenum to promote mixing of the air, over a chill rack containing the test specimens, and out through a flexible, vinyl exhaust line (10.2-cm diameter). This airflow pattern is the same for all five chambers.

The exhausted air from each chamber passes into a central air exhaust duct and then to an outlet containing charcoal and Purafil filters. The Purafil filter is a chemical system that combines with contaminants that the charcoal filter does not absorb. The decontaminated air exhausts directly to the outside environment.

If an interruption in the flow of air in the environmental system should occur, an airflow sensor, mounted in the duct between the filtering and cooling sections, automatically deenergizes the entire system and closes off the pollutant supply lines. This feature prevents buildup within the exposure chambers of pollutant concentrations that could result in personnel injury and damage to on-going exposure experiments.

EXPOSURE CHAMBERS

Each of the exposure chambers (Figure 2) has an inside volume of 1.10 m³ and is covered externally with 10.2- to 12.7-cm-thick polyurethane foam insulation (a self-extinguishing material). Each chamber contains a xenon arc lamp (6000 watts) to simulate sunlight. A cap on top of the chamber houses the lamp, and clear FEP Teflon film (1 mm thick) separates the light from the environmental conditions within the chamber. This kind of film was selected because it transmits practically all of the ultraviolet, visible, and infrared radiation emitted by xenon lamps. Each chamber also contains a chill rack (Figure 3) upon which the test specimens are mounted.

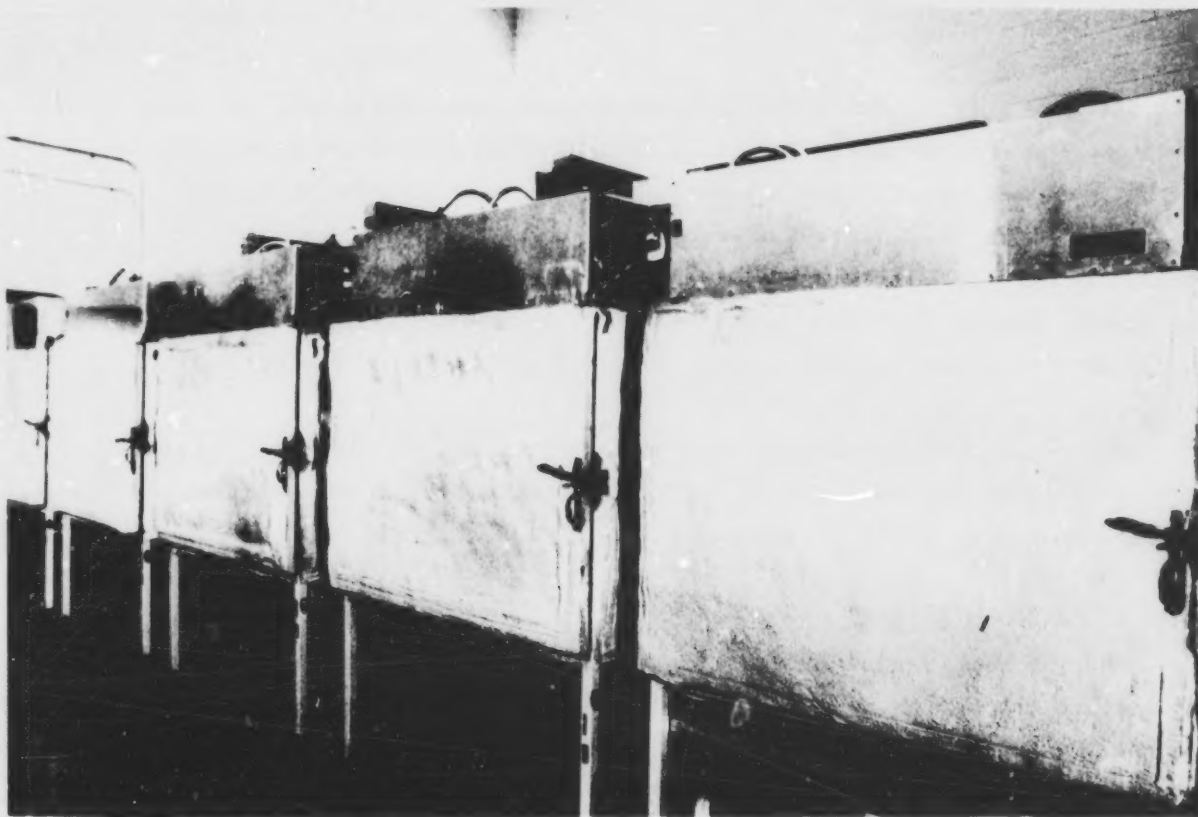


Figure 2. Environmental exposure chambers.

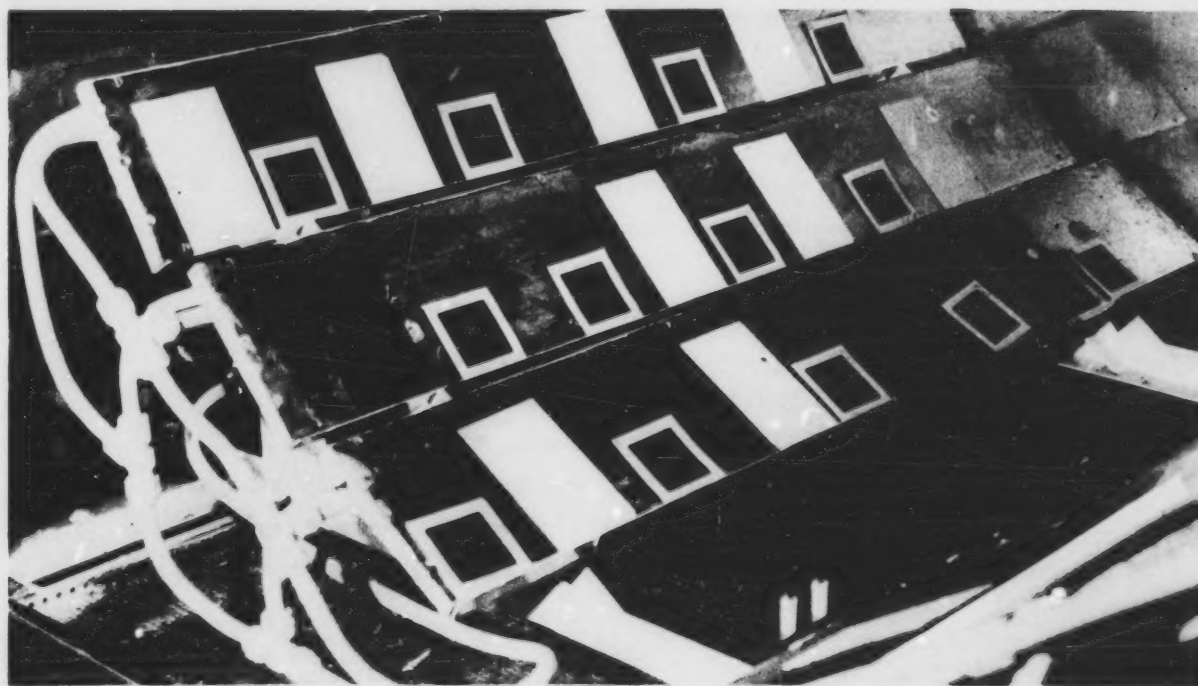


Figure 3. Exposure chill racks.

With the lamp off, coolant circulates through the rack; this cools the test specimens and results in the formation of dew. When coolant stops circulating, the lamp comes on and the dew evaporates from the test specimens. Appendix B shows the interfacing of the lamp power units and chamber chill racks. Two of the lamp power units are shared by four chambers; the remaining chamber has an individual unit. A safety device protects each power supply and xenon lamp against coolant overheating or loss of coolant pressure.

An interlock switch on each chamber door cuts off the lamp if personnel open the door during the light cycle, thus protecting their eyes against ultraviolet radiation.

POLLUTANT CONTROL SYSTEM

The pollutant control system consists of a source and controller for each of the three gaseous pollutants. The purpose of the system is to continuously dispense, monitor, and control the desired level of sulfur dioxide, nitrogen dioxide, and ozone concentrations within each of the environmental exposure chambers. In this report, no attempt is made to determine concentrations of the reaction products of these gaseous pollutants. However, product concentrations can be determined since the reaction rates for these pollutants are known.²

Pollutant Sources

Cylinders of liquid nitrogen tetroxide (N_2O_4) and sulfur dioxide (SO_2) serve as sources for gaseous nitrogen dioxide and sulfur dioxide, respectively. The cylinders, along with dilution tanks (Figure 4), are housed in a cabinet with an exhaust system to remove fumes in the event of line leakage. Both cylinders are maintained at constant temperatures. Schematics of the electrical wiring and gas lines, with a description of nitrogen dioxide and sulfur dioxide pollutant source components, are shown in Appendixes C and D, respectively. The two schemes are basically similar except for several minor differences in gas line connections. They operate by diluting regulated flows of concentrated polluted gas with compressed

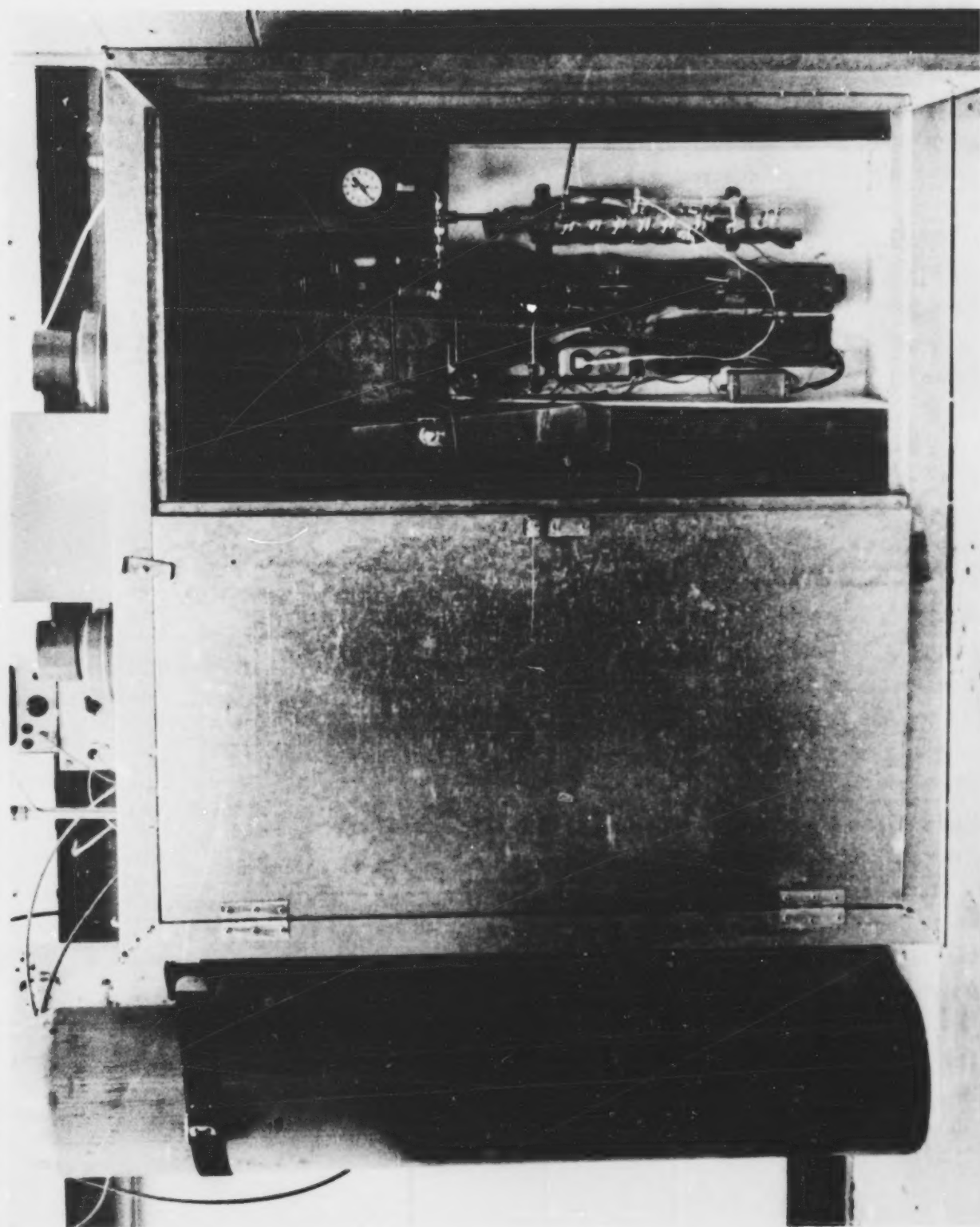


Figure 4. Dilution system.

air in a dilution tank representing a low-pressure sink. The pressure within the dilution tank, which has three compartments to facilitate mixing, is automatically maintained between set limits. The diluted gas, which is about 20 percent pollutant, then flows at a reduced pressure (~ 3 psig) to the respective pollutant controller, which distributes the gas (at different rates depending on desired concentration) to the mixing box of each chamber. The interfacing of the dilution source with the controllers is shown in Appendix B.

A modified ozone generator produces ozone by exposing dry air to a high-voltage discharge (commonly referred to as a silent arc discharge generator). Concentrations of ozone up to 5 ppm per chamber are readily available with this unit. No dilution system is necessary. The generator is operated with dry air and a voltage setting that minimizes the formation of oxides of nitrogen (NO_x). A chemiluminescence analyzer was unable to detect NO_x formation within the environmental chambers.

The pollutant source design contains several safety features to protect personnel and the environmental exposure system. The cylinders of SO_2 and N_2O_4 have thermal and pressure cutout devices to prevent exceeding predetermined conditions. In the event of momentary loss of power to the environmental system, a sensor automatically cuts off the flow of the three pollutant gases to the controller. This feature prevents the accumulation of high concentrations of pollutants in the chambers.

Pollutant Controllers

The pollutant controllers (Figure 5) are identical except for the pollutant analyzers, which are specific for each of the three pollutant gases. Chamber concentrations of nitrogen dioxide and ozone are monitored by chemiluminescence analyzers and sulfur dioxide is monitored by flame photometric detection. Each analyzer samples the chambers one at a time; a synchronized stepping switch operating solenoid valves automatically maintains the sequence of chamber sampling.

The controllers are equipped with adjustable sample and control timers (sample and control modes of operation). The sampler timer allows the analyzer to stabilize at the level of pollutant concentration in the chamber

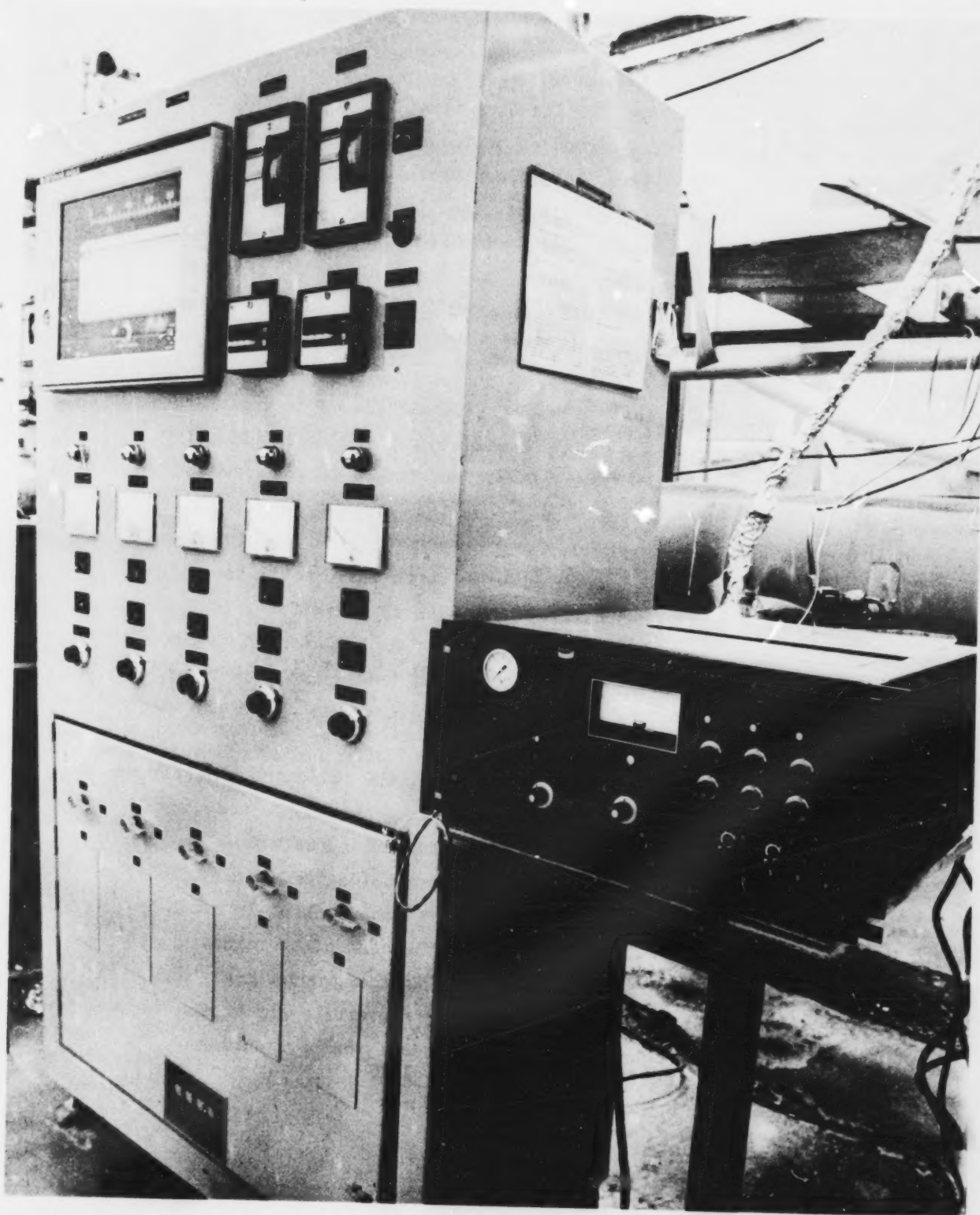


Figure 5. Pollutant controller.

being sampled. At the end of the stabilization time, the control timer begins the control function. The amount of pollutant, as determined from a signal transmitted by the analyzer, is balanced against a preset potentiometer that has been calibrated for pollutant concentration. The difference or imbalance is transmitted by a silicone controlled rectifier (SCR) system to a servo valve that opens or closes depending on the direction required. The simplified circuit of the controller is shown in Appendix E. The interfacing of the controllers with the pollutant sources and environmental chambers is shown in Appendix B.

During the initial start-up of a chamber, the imbalance is great since the concentration of pollutant is low in the chamber. The pollutant servo valve opens on a time basis that is adjustable and preset by the control timer. Once the pollutant concentration is near the desired level (the difference or imbalance has narrowed), the proportional band that is adjustable in the SCR system limits the travel of the servo valve until the adjustable "dead band" (no control action taken) is reached. Therefore, in the control mode of operation, the controller functions as both a step system - opening the pollutant servo valve a set interval of time - and as a proportional system - opening the pollutant servo valve a proportional amount as determined by the imbalance.

Following the initial sample and control time, the pollutant controller switches automatically to the next chamber and begins the sample and control modes of operation. The sequence is repeated continuously for the five chambers. As the controller approaches the set point (desired level of pollutant concentration) for each chamber, proportional control is established and maintained for the exposure period. The controller maintains the desired pollutant concentration by operating in the proportional band.

Each of the pollutant controllers has means to override any of the automatic operations, including by-passing individual chambers during sequencing.

CHAMBER EVALUATION AND OPERATION

The experimental results of a chamber exposure study will only be as good as the control system. Before proceeding with exposure experiments to determine pollutant damage to materials, the control capability of the environmental variables as well as the chamber distribution of light energy and pollution concentration were minimized below 10 percent for 95 percent of the measurements. This level of variability was considered acceptable for conducting material-effects research. Statistical techniques were used to determine what parts of the environmental control system needed adjustment.

CHAMBER LIGHTING

The energy distribution from the xenon lamp within the chambers was measured and recorded as millivolts by a Talley Industries SOL-A-Meter. The distribution of energy on the specimen racks within the five chambers was initially balanced by: (1) varying the lamp wattage, (2) placing reflectors in the light cap, and (3) varying the angle of the specimen rack. Analysis of variance (Table 1) was conducted on the energy data to determine chamber and position effects.

Table 1. ANALYSIS OF VARIANCE FOR INITIAL LAMP ENERGY DATA

Source	Sum of squares	Degrees of freedom	Mean squares	F calc.	F table
Position	311.9379	17	18.3493	6.05	1.76 ^a
Chamber	49.4749	4	12.3687	4.08	2.05 ^a
Residual ^b	206.2371	68	3.0229		
Total	567.6499	89	6.3781		

^a0.05 probability level.

^bResidual is confounded with a possible chamber times position interaction effect because the experiment was not replicated. It is taken as the error term in calculating F values.

The calculated F statistics determined for the positions on the specimen racks and the chambers exceed the Table F value (0.05 probability level). Therefore, the observed differences for the positions and chambers are statistically significant and caused by something other than random error. The best estimate of the overall mean ($\bar{x}$) energy was 63.28 millivolts. Based on 89 degrees of freedom, the standard deviation (2S) is 5.05. The coefficient of variation is 4 percent. With these tolerance limits, we can be 95 percent certain that less than 10 percent variation from the mean energy may be expected from 95 percent of the measurements.

High energy readings at particular positions were lowered by selectively reducing the reflectivity of the walls with a light spray of flat, black paint. Individual lamp wattages were adjusted to reduce differences among chambers. Analysis of variance (Table 2) was performed on the new data for the five chambers.

Table 2. ANALYSIS OF VARIANCE FOR LAMP ENERGY DATA

Source	Sum of squares	Degrees of freedom	Mean squares	F calc.	F table
Position	55.5960	17	3.2704	2.05	1.76 ^a
Chamber	5.7005	4	1.4251	1.09	2.50 ^a
Residual ^b	89.0596	68	1.3097		
Total	150.3560	89	1.6894		

^a0.05 probability level.

^bResidual is confounded with a possible chamber times position interaction effect because the experiment was not replicated. It is taken as the error term in calculating the F values.

The calculated F statistics (Table 2) now reveal that the chamber differences are statistically insignificant. The position effect, however, is still significant at the 0.05 probability level. The best estimate of the overall mean ($\bar{x}$) energy was 61.51 millivolts with a standard deviation (2S) of 3.38 for 89 degrees of freedom. The coefficient of variation is 3 percent. With these tolerance limits, we can be 95 percent certain that less than a 6.8 percent variation from the mean energy exists for 95 percent

of the measurements. This relatively small amount of variability does not warrant the stratification of position as a variable. Placing the material test specimens randomly within each of the five chambers minimizes any bias that could be caused by the position effect.

POLLUTANT DISTRIBUTION

It is essential that the movement of polluted air be uniformly distributed across the test specimens. The airflow from each chamber was measured in the exhaust ducts with a pitot tube and was balanced by adjusting a vane installed in the chamber air supply duct.

To establish the distribution pattern of polluted air within the chambers, blue colored test fabrics were placed at various locations within the chambers about 15.24 cm above the base and parallel to the airflow. The test fabric was developed by the American Association of Textile Chemists and Colorists and changes color on exposure to nitrogen dioxide. All five chambers were operated with no dew/light at the following constant conditions:

Temperature	35°C
Relative humidity	5 percent
Nitrogen dioxide	940 $\mu\text{g}/\text{m}^3$
Airflow	1.13 m^3/min per change

After 48 hours of exposure, color changes of the fabric samples were measured photoelectrically with a Hunter Model D 25A Color Difference Meter. Statistical computation of mean fade and standard deviation indicated that pollutant distribution was not balanced within the five chambers.

A plenum (sheet of aluminum with 0.74-cm-diameter holes spaced 2.5 cm apart) was next installed about 12.7 cm above the base of the chamber. The plenum creates a pressure drop in the movement of air across it, thereby facilitating the mixing of pollutants within the chambers. The pressure drop across the plenum was measured and balanced for the five chambers. The exposure of the test fabric was repeated. An analysis of variance (Table 3) was conducted on the new data to determine the significance of chamber and position effects.

Table 3. ANALYSIS OF VARIANCE FOR POLLUTANT (NO₂)
DISTRIBUTION WITHIN THE CHAMBERS

Source	Sum of squares	Degrees of freedom	Mean square	F calc.	F table
Position	0.02344	8	0.00293	3.84	2.25 ^a
Chamber	0.00424	4	0.00106	1.40	2.67 ^a
Residual ^b	0.02441	32	0.00076		
Total	0.05209	44	0.00118		

^a0.05 probability level.

^bResidual is confounded with a possible chamber times position interaction effect because the experiment was not replicated. It is taken as the error term in calculating F values.

The calculated F statistic (Table 3) for the pollutant distribution within the chambers indicates that the chamber effect is statistically insignificant; however, position effects exist at the 0.05 probability level. The best estimate of the overall mean ($\bar{x}$) for the Δ values was 3.50 with a standard deviation (2S) of 0.069 for 8 degrees of freedom. The coefficient of variation is 1 percent. With these tolerance limits, we can be 95 percent certain that less than a 2.25 percent variation from the mean fade is expected for 95 percent of the measurements. Again, randomly placing the test specimens within the chambers minimizes bias that this variable may cause.

CONTROL OF ENVIRONMENTAL VARIABLES

Tested control points and the resulting control capabilities of the environmental variables are shown in Table 4.

Air temperature and humidity are controlled in the air stream (mixing box) entering each environmental chamber. During the cycle of dew and light, the air temperature and humidity within the chambers are allowed to fluctuate, thereby simulating diurnal conditions; but the desired concentration of each gaseous pollutant is monitored and controlled within the chambers during the dew/light cycle by the controller system.

The control capability was computed from data obtained from a strip chart during 24 hours of continuous dew/light (20 minutes) exposure. The

variability (2S) for the control capability of the environmental variables appears to increase with the mean level ($\bar{x}$). This is frequently encountered in automatic controlled experimentation and should pose no problem in the computation of exposure data. The variation of the five variables is within the acceptable limit of 10 percent.

Table 4. CONTROL CAPABILITY OF ENVIRONMENTAL VARIABLES^a

Environmental variable	Control point	Control capability	
		$\bar{x}$	2S
Temperature, C ^o ^b	35	34.8	+2
Humidity, percent ^b	90	88.8	+2.2
	50	50.4	+1.1
Ozone, $\mu\text{g}/\text{m}^3$	980	991.8	+31.4
	196	199.9	+11.8
Sulfur dioxide, $\mu\text{g}/\text{m}^3$	1310	1372.9	+131.0
	262	275.1	+23.6
Nitrogen dioxide, $\mu\text{g}/\text{m}^3$	940	930.6	+26.3

^aEach of the five chambers was operated with a 20-minute dew/light cycle.

^bControlled in mixing box.

SUMMARY

An environmental system for controlling the temperature, humidity, and concentration of gaseous pollutants within five chambers has been designed and assembled. The environmental system was basically designed to assess the effects of gaseous air pollutants on materials; the operational capabilities, however, could benefit other laboratories conducting controlled environmental experimentation. In addition, statistical techniques were utilized to reduce chamber differences in lighting and pollutant distribution to below 10 percent variation for 95 percent of the measurements. This feature was necessary before planned exposure studies could be initiated and should be of interest to those researchers collecting effects data from chamber exposure studies.

REFERENCES

1. Clean Air Amendments of 1970. Public Law 91 604. December 31, 1970.
2. Leighton, P.A. Photochemistry of Air Pollution. New York, Academic Press, 1961.

APPENDIX A:
ENVIRONMENTAL COMPONENTS

AIR CONDITIONING SYSTEM

- Farr, Type J-12 Prefilter and Type 200 Particulate Filter
- Barneby-Cheney, Type FMA Charcoal Filter Cell
- Dunham-Bush, Package Chiller, 5 tons
- Westinghouse Electric, WAF-1824-6D Aluminum Water Coil
- ILG Industries, Type BCF Blower, Size 2000

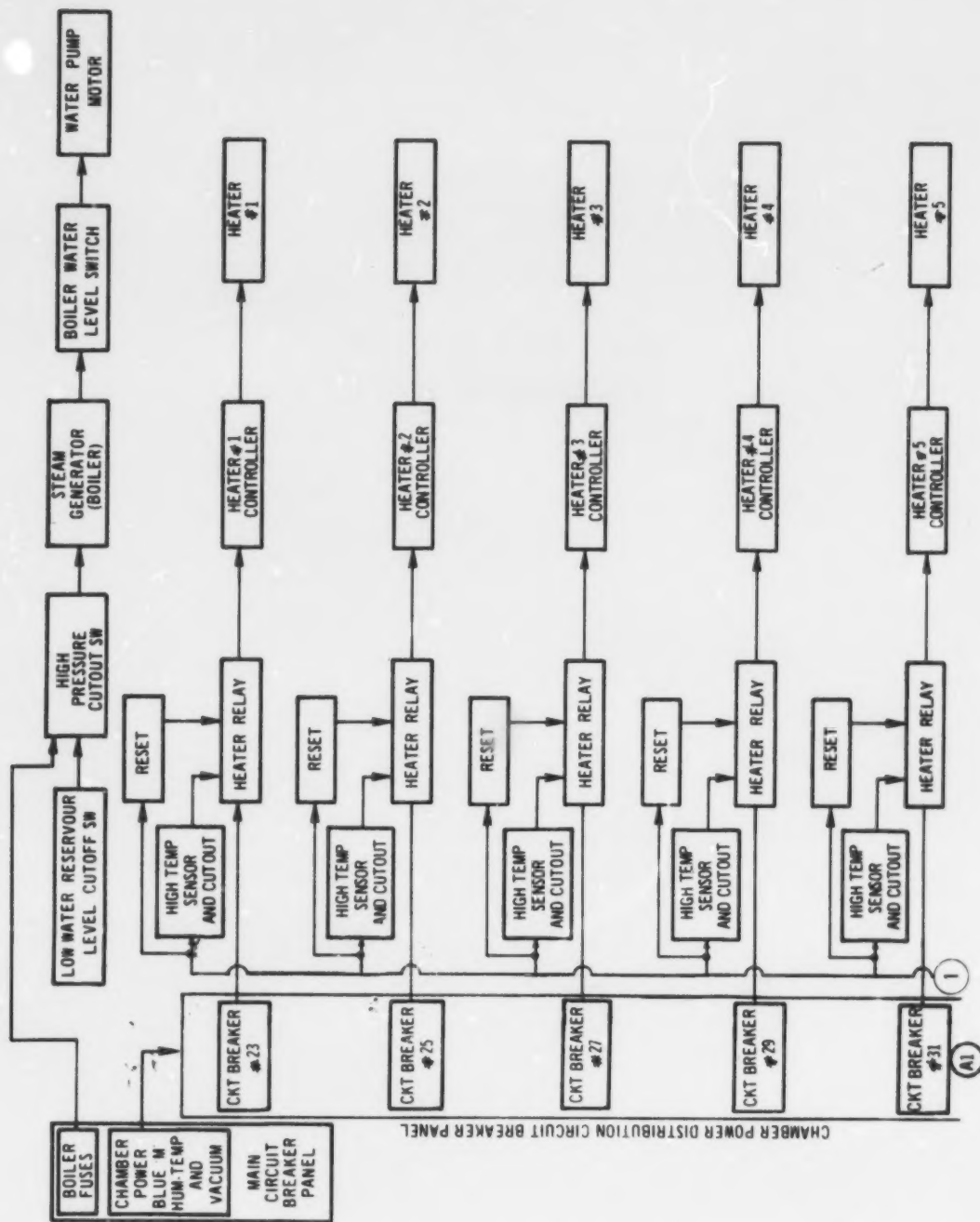
AIR RECONDITIONING SYSTEM

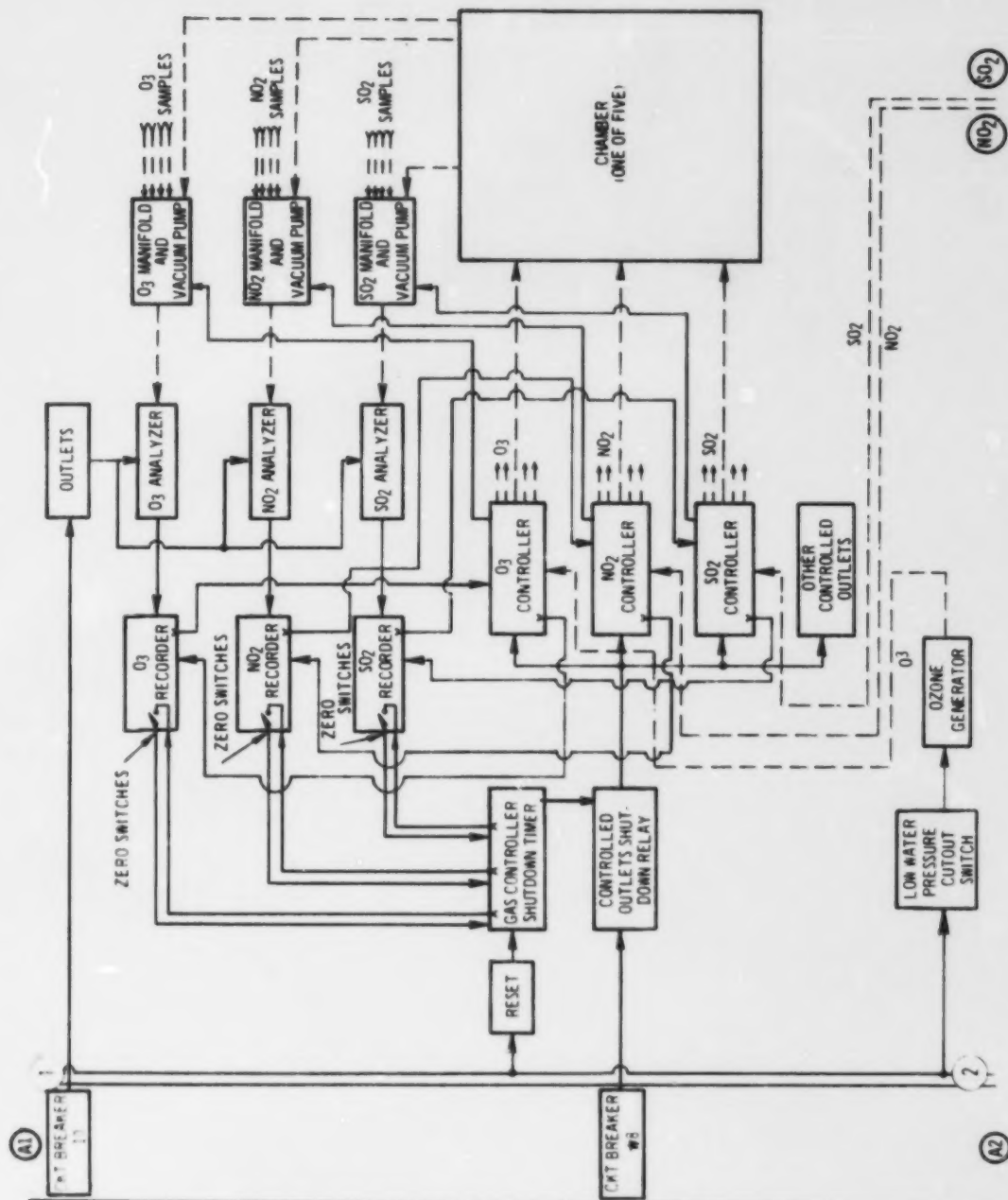
- Edwin L. Weigend, Model CAB-62 Duct Type Heater
- Barber-Coleman, CP 5409-208 Solid State Proportional Temperature Controller, ESP 6111 Solid State Receiver Controller, ESP 6861 Solid State Transmitter, ASAP 301 Power Supply, and Ts 5229 Temperature Sensor
- Fluid Flow Products, Model 2331F4B Motorized Steam Valve Hydrodynamics, Model 15-3226 Humistat and Narrow Range Humidity Sensors
- Edwin L. Weigend, Model CES 72 Boiler, Chromalox Electric
- Honeywell, Model Y153836-(24)-(48)-0-000-002-10-002-181-062 Recorder, Temperature Sensor, and Relative Humidity Gold Grid Sensor
- Adgo, Gaseous Pollutant Controllers
- Bendix Process Instrumentations, Model 8300 Total Sulfur Analyzer, Model 8101-B Oxides of Nitrogen Analyzer, and Model 8002 Ozone Analyzer
- Welbach Ozone Generator, W-10 Unit
- Atlas Electric Devices, Model RM-60 Xenon Arc System (6000 watts)

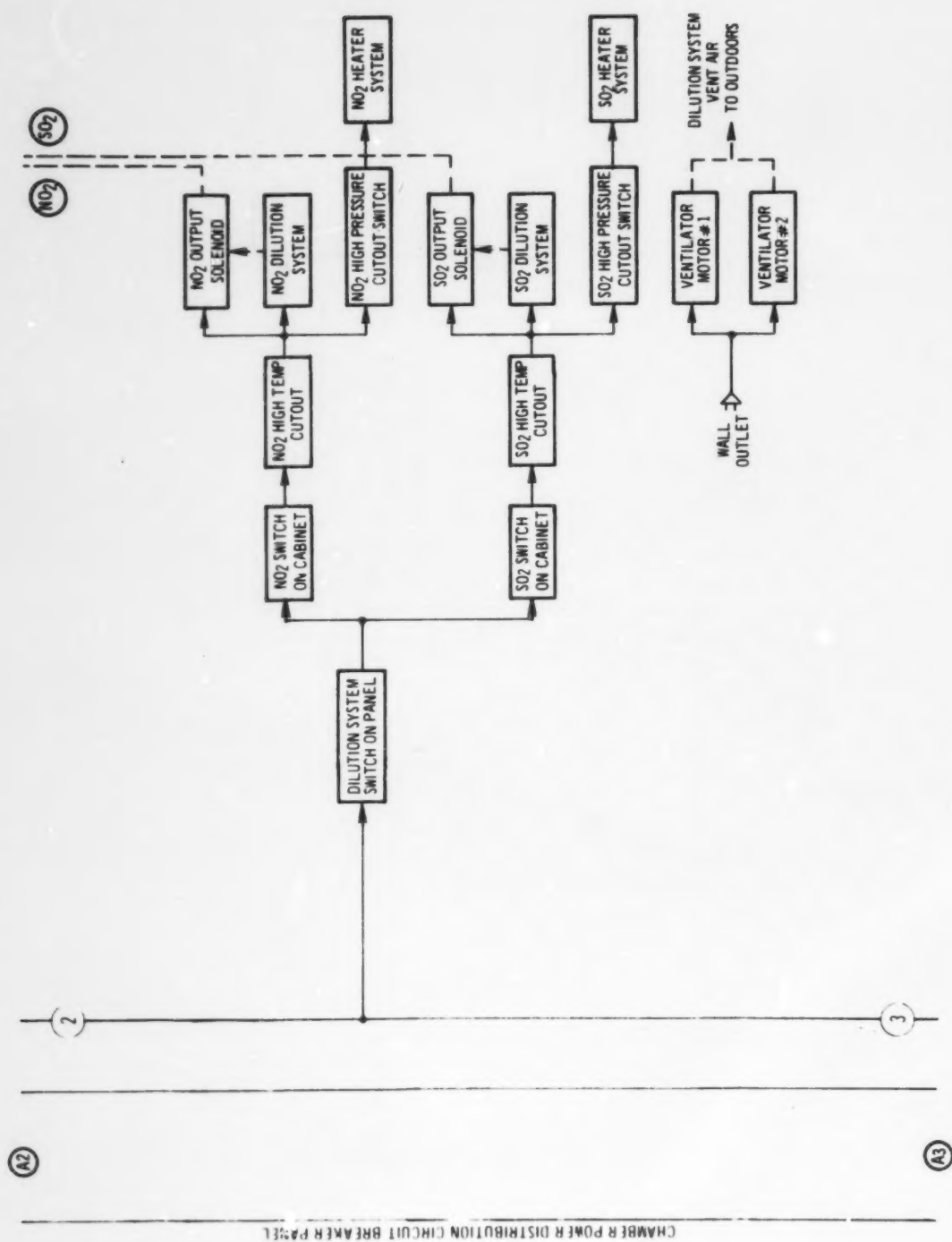
AIR EXHAUST SYSTEM

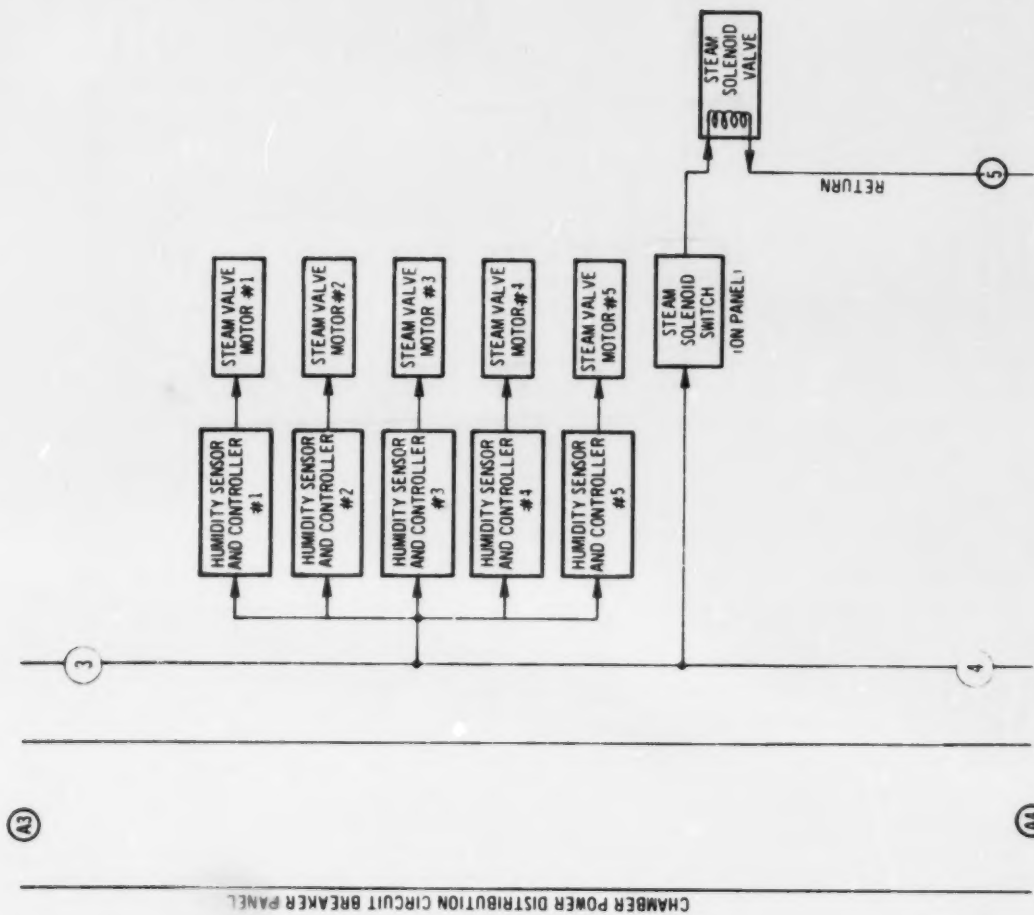
- Barneby-Cheney, Type FMA Charcoal Filter
- Burrough and Associates, IC-22A Purafil Chemical Filter

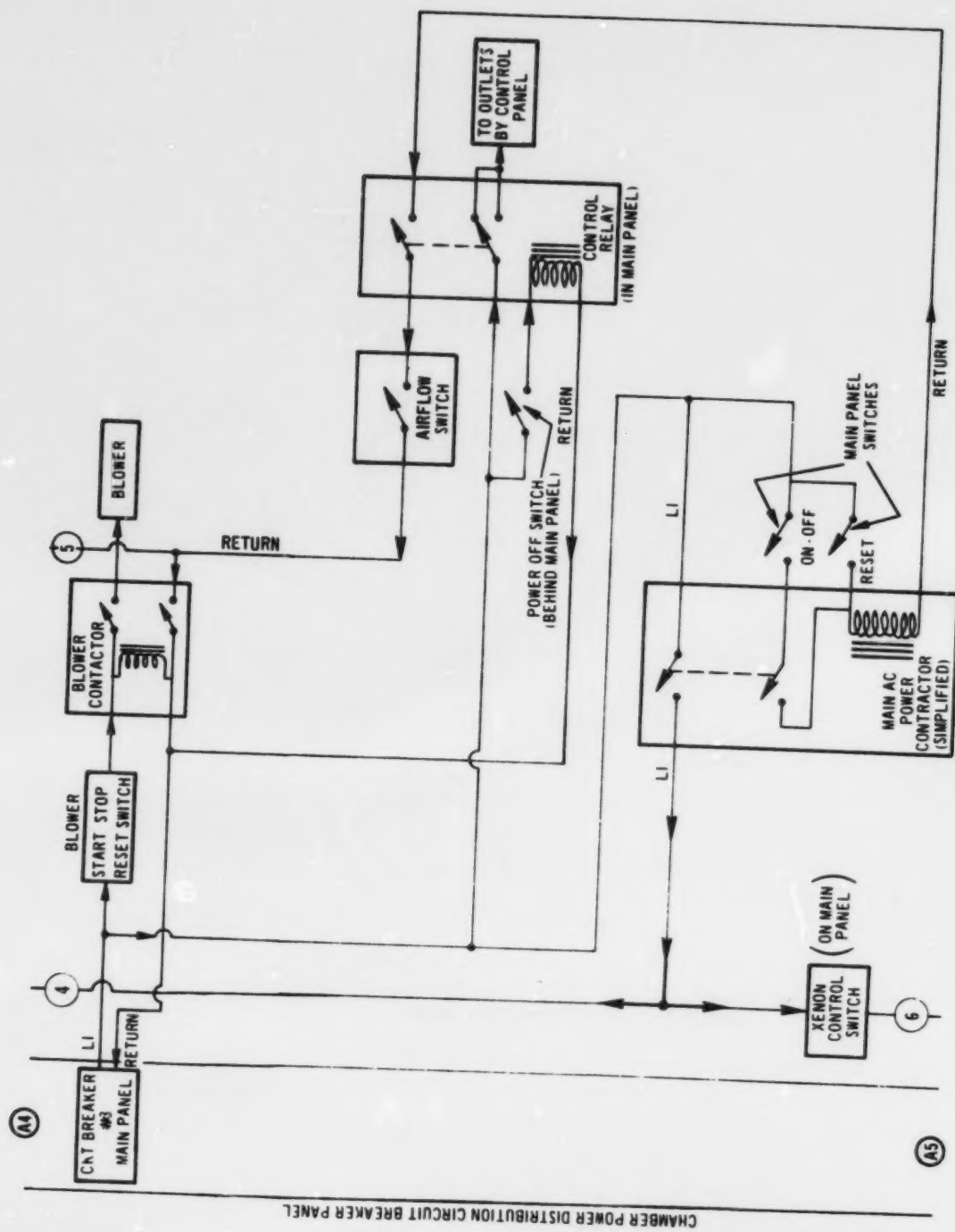
APPENDIX B:
POWER DISTRIBUTION OF
ENVIRONMENTAL SYSTEM

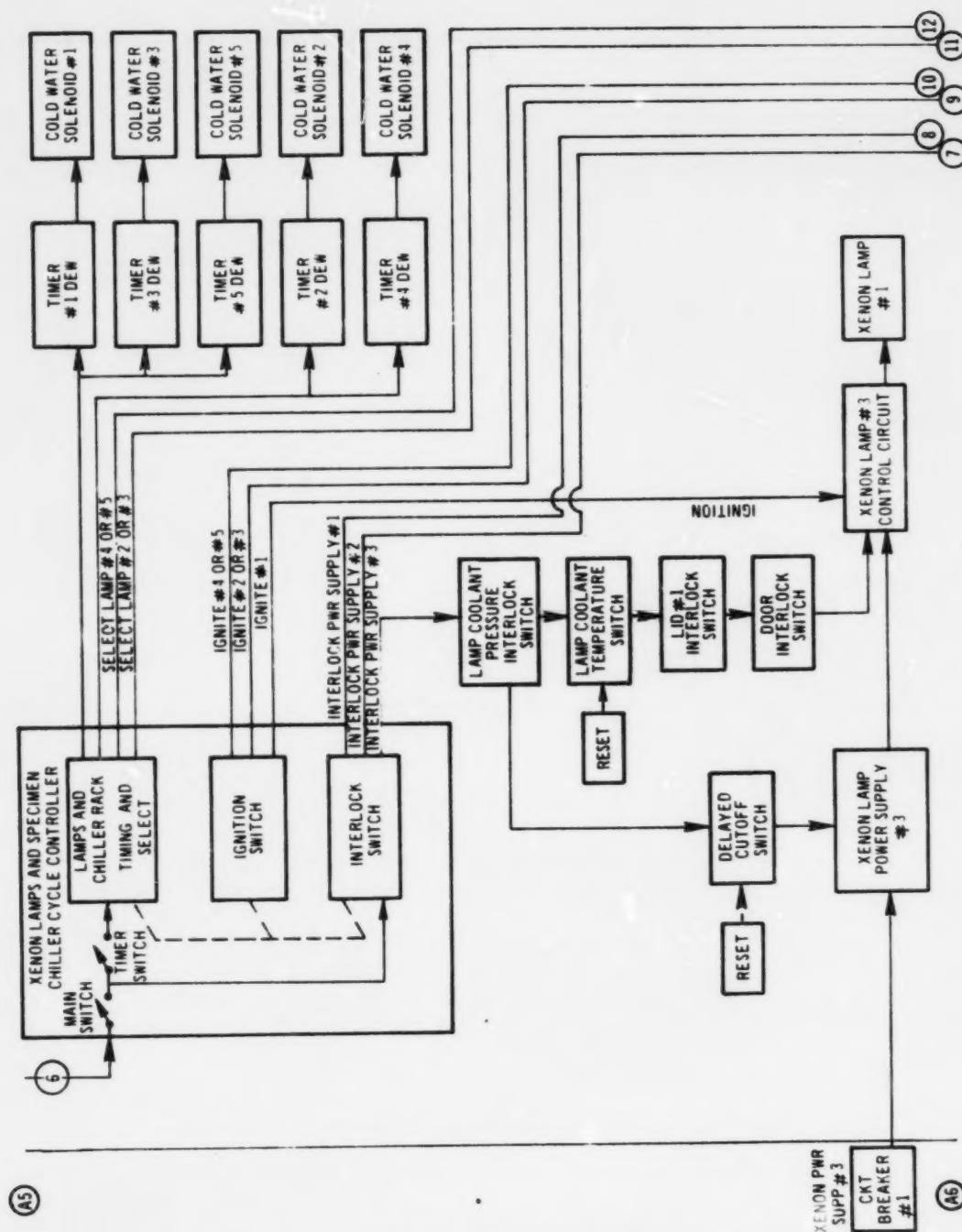


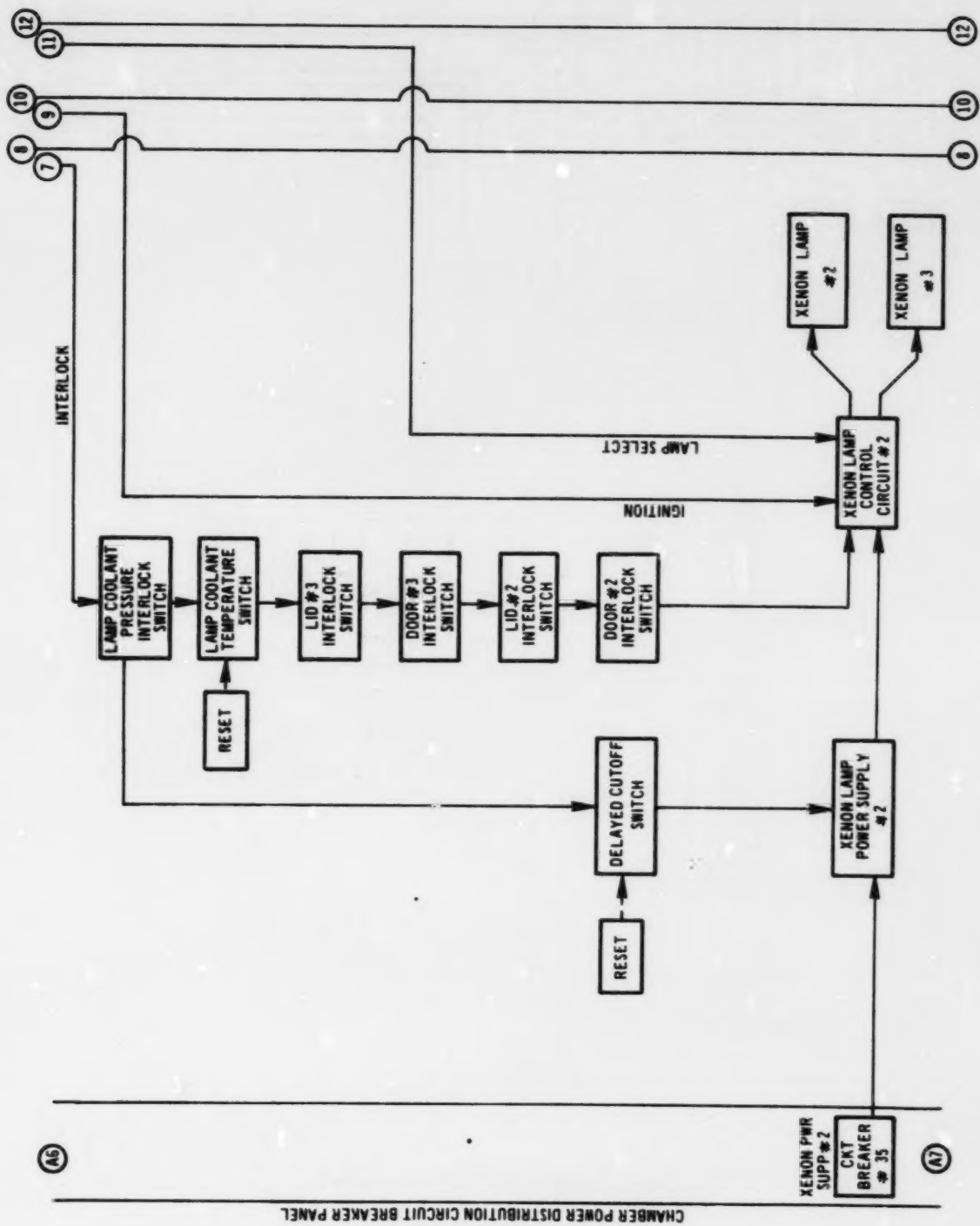


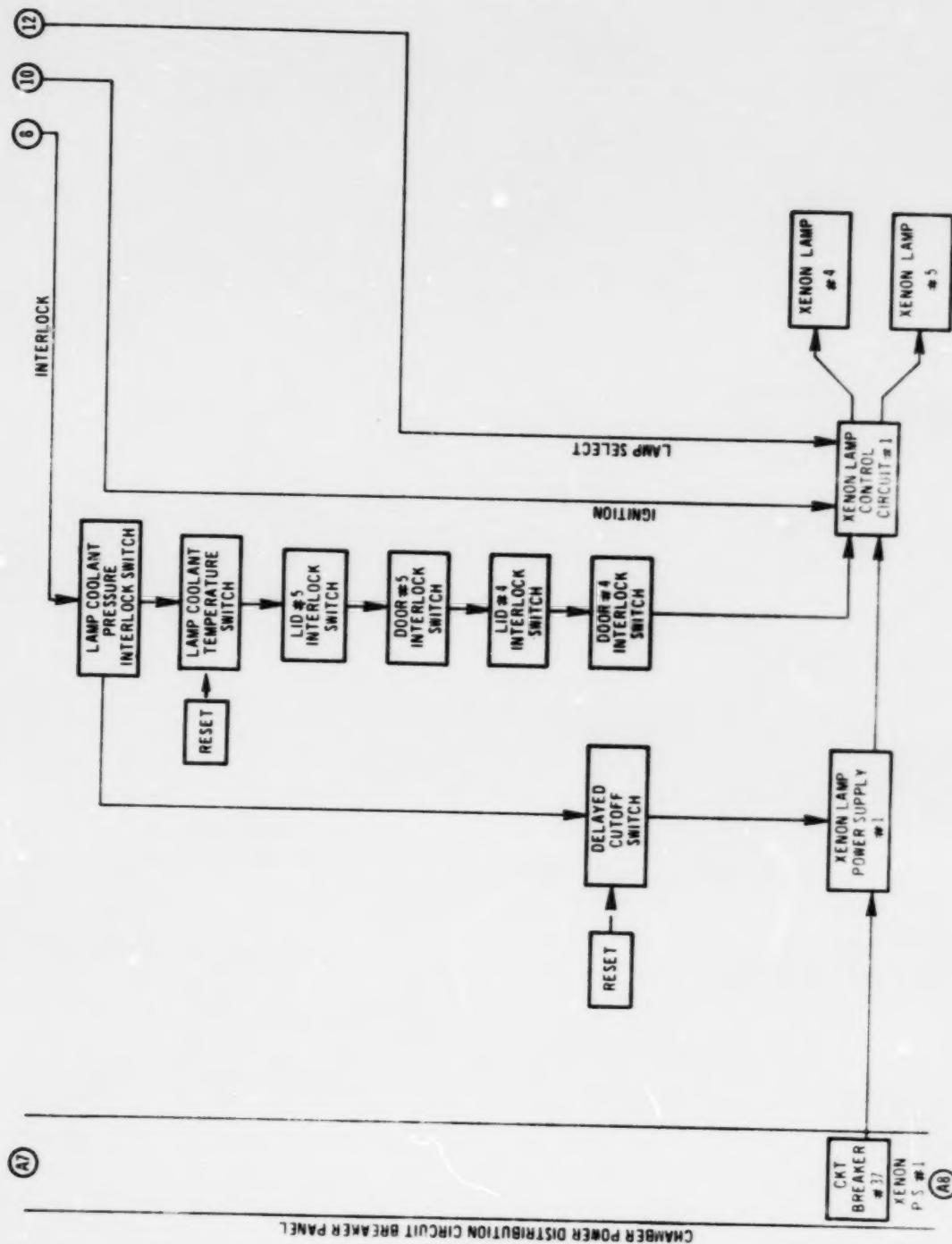


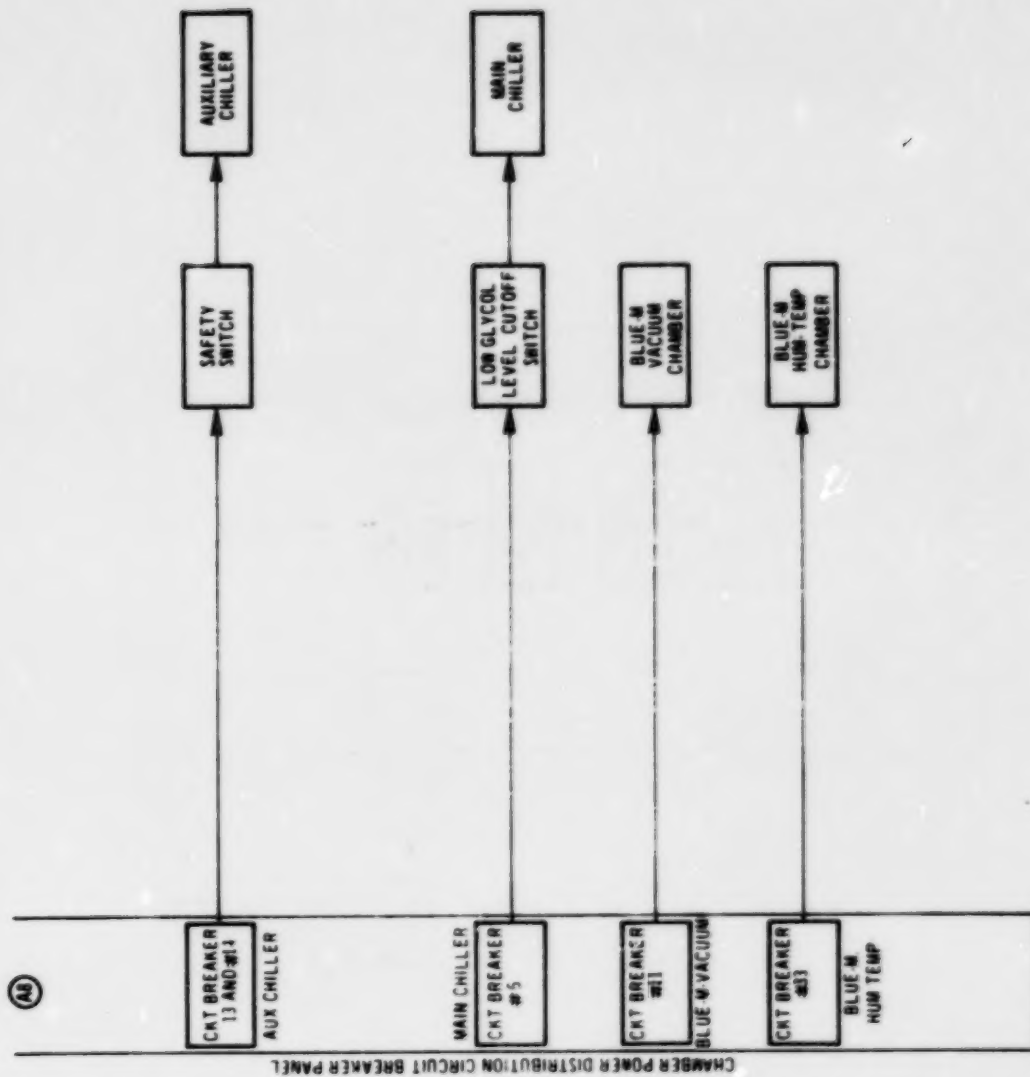




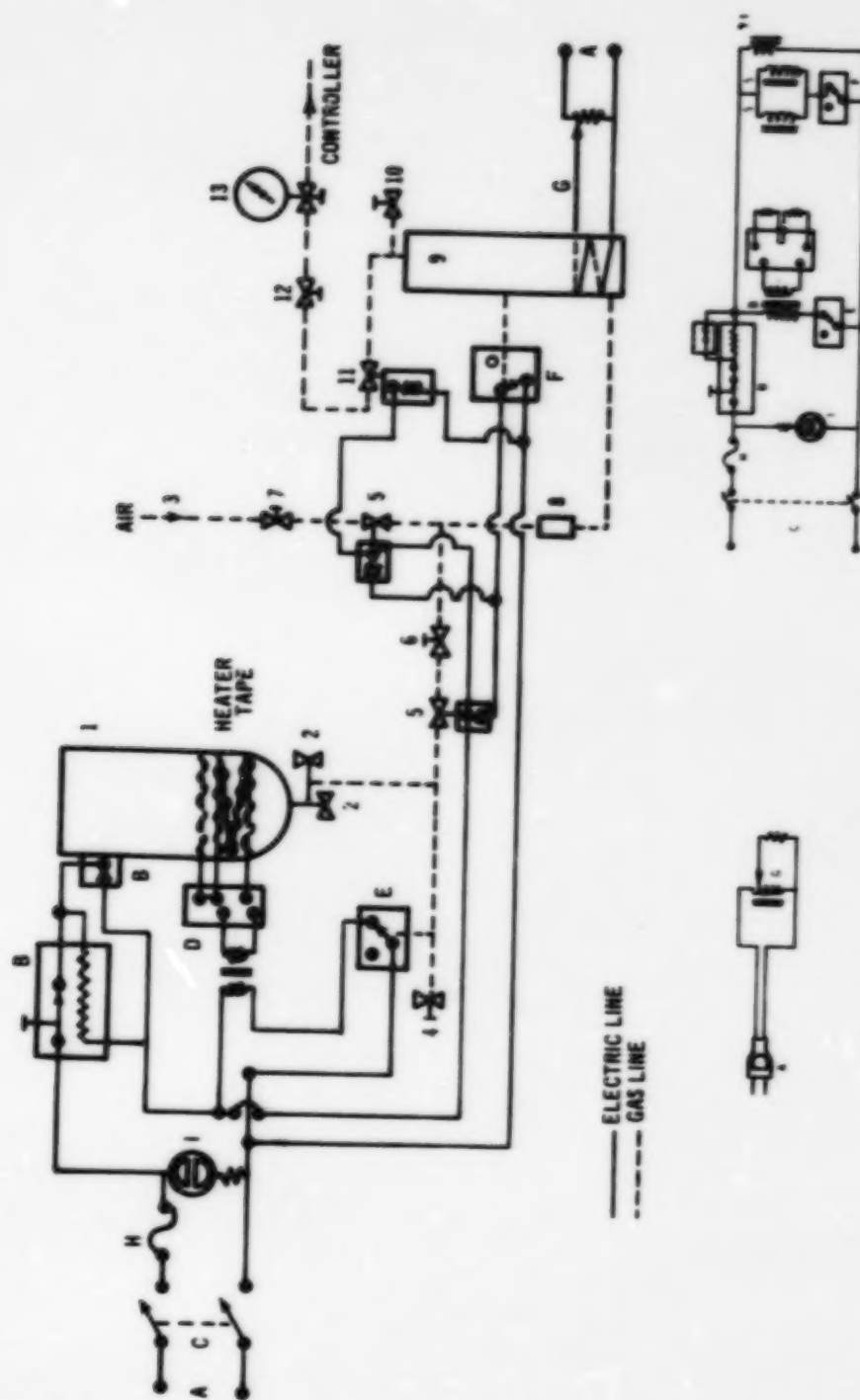








APPENDIX C:
ELECTRICAL AND GAS LINE SCHEMATICS
FOR NITROGEN DIOXIDE DILUTION SYSTEM



ELECTRICAL CIRCUITRY

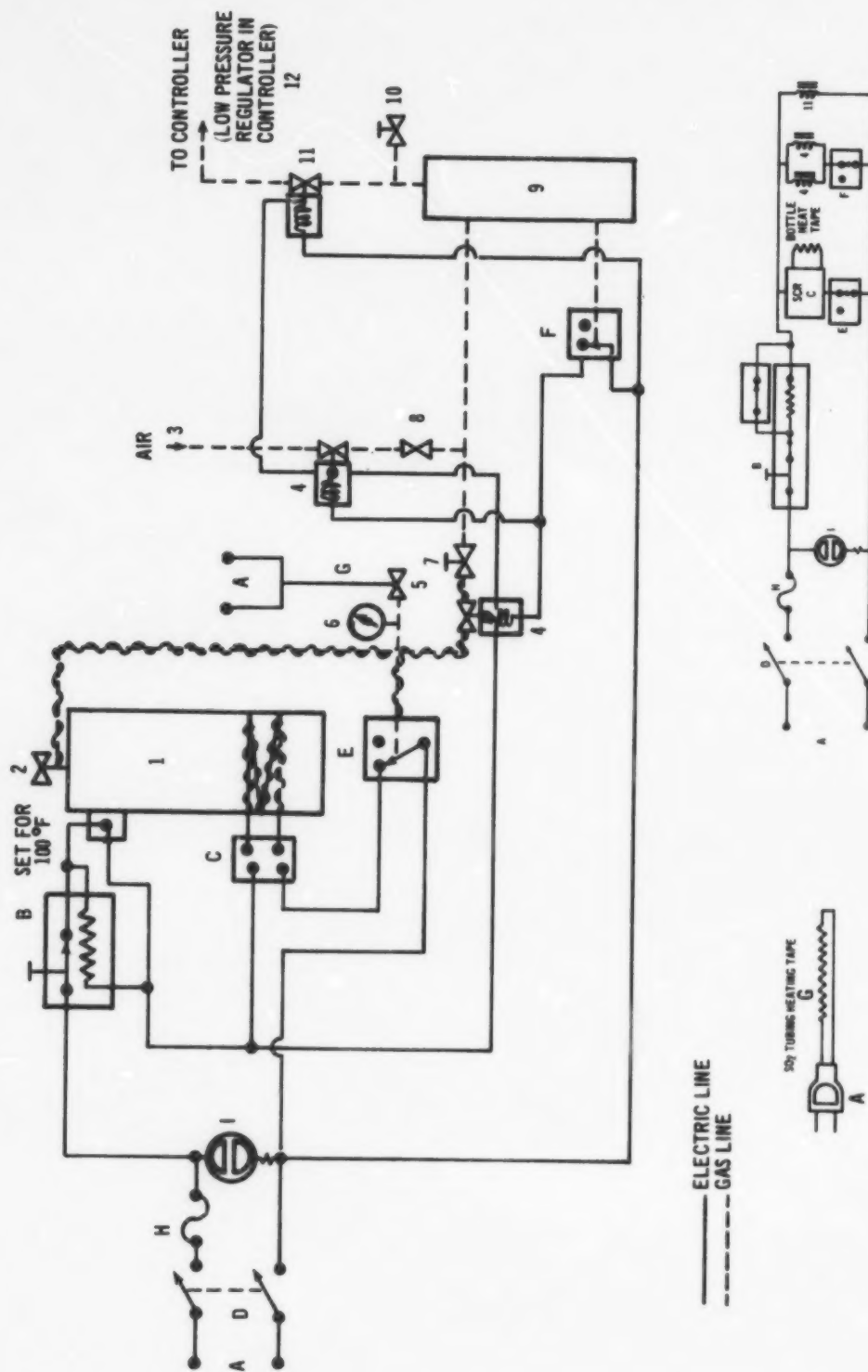
- A. 110-volt ac electrical line.
- B. Thermo-overcurrent circuit breaker (0.1 amp) and sensing thermostat with manual reset - cuts off current to heater tape and gas solenoid valve when nitrogen tetroxide (N_2O_4) cylinder temperature exceeds a predetermined temperature.
- C. Toggle switch (located on top of the vented cabinet) - manual switch that deenergizes dilution system.
- D. SCR thermo-controller (208 volts) transformer and heater tape - maintains nitrogen tetroxide cylinder at 120°F.
- E. Overpressure cutout switch with automatic reset - cuts off current to SCR thermo-controller and heater tape when pressure of the nitrogen tetroxide cylinder exceeds a predetermined pressure.
- F. Dilution pressure control switch - opens and closes both air and nitrogen dioxide solenoid valves to maintain the dilution tank pressure in the preselected range.
- G. Heating tape and control Variac - keeps dilution tank above ambient room temperature.
- H. Circuit protective 3-amp fuse.
- I. Neon bulb - indicates system is energized.

GAS LINE

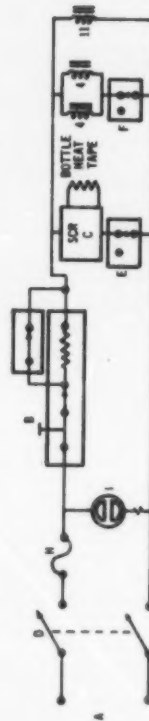
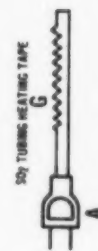
- 1. Cylinder of nitrogen tetroxide (N_2O_4).
- 2. Manual valves on nitrogen tetroxide cylinder.
- 3. Compressed air line - maintained at 30 psig.
- 4. Manual valve - permits venting nitrogen dioxide line.
- 5. Solenoid valves with pressure control switch - supplies air and nitrogen dioxide gas when dilution tank pressure drops below 20 psig.
- 6. Manual valve (nitrogen dioxide line) - allows flow adjustment of nitrogen dioxide gas (100 percent) to dilution tank.
- 7. Manual valve (air line) - allows flow adjustment of compressed air to dilution tank.
- 8. Short length of Teflon tubing - permits observing flow of diluted gas to tank.

9. Dilution tank - supplies nitrogen dioxide gas (20 percent) in pressure range of 20 to 29 psig.
10. Manual valve - permits venting of the dilution tank.
11. Solenoid valve - stops flow of diluted nitrogen dioxide gas to controller if power failure occurs.
12. Manual valve - off/on valve in diluted gas line.
13. Low-pressure regulator - maintains pressure of 3 psig of diluted nitrogen dioxide gas to controller.

APPENDIX D:
ELECTRICAL AND GAS LINE SCHEMATICS
FOR SULFUR DIOXIDE DILUTION SYSTEM



— ELECTRIC LINE
 --- GAS LINE



ELECTRICAL CIRCUITRY

- A. 110-volt ac electrical line.
- B. Thermo-overcurrent circuit breaker (0.1 amp) and sensing thermostat with manual reset - cuts off current to heater tape and gas solenoid valves when sulfur dioxide (SO_2) cylinder temperature rises above a predetermined temperature.
- C. SCR thermo-controller (110 volts) and heater tape - maintains sulfur dioxide cylinder at 90°F.
- D. Toggle switch (located on top of the vented cabinet) - manual switch that deenergizes dilution system.
- E. Overpressure cutout switch with automatic reset - cuts off current to SCR thermo-controller and heater tape when line pressure exceeds a predetermined pressure.
- F. Dilution pressure control switch - opens/closes both air and sulfur dioxide solenoid valves to maintain dilution pressure in the preselected range.
- G. Heater tape on sulfur dioxide lines - maintains lines above ambient room temperature to prevent condensing of the sulfur dioxide.
- H. Circuit protective 3-amp fuse.
- I. Neon bulb - indicates system is energized.

GAS LINE

- 1. Cylinder of liquid sulfur dioxide (SO_2).
- 2. Manual valves on sulfur dioxide cylinder.
- 3. Compressed air line - maintained at 46 psig.
- 4. Solenoid valves with pressure control switch - supplies air and sulfur dioxide gas (100 percent) when dilution tank pressure drops below 32 psig.
- 5. Manual valve - permits venting of sulfur dioxide gas (100 percent).
- 6. Pressure gauge - monitors pressure in the sulfur dioxide cylinder.
- 7. Manual valve (sulfur dioxide line) - allows flow adjustment of sulfur dioxide gas (100 percent) to dilution tank.
- 8. Manual valve (air line) - allows flow adjustment of air to dilution tank.

9. Dilution tank - supplies sulfur dioxide gas (v20 percent) in pressure range of 32 to 39 psig.
10. Manual valve - allows contents of dilution tank to be vented.
11. Solenoid valve - stops flow of diluted gas to controller if power failure occurs.
12. Low-pressure regulator - maintains pressure of 3 psig of diluted sulfur dioxide gas to controller.

APPENDIX E:
SIMPLIFIED CIRCUITRY OF
POLLUTANT CONTROLLER

